BURNING CHARACTERISTICS OF PARTIALLY DEVOLATILIZED COALS

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INTRODUCTION

Thermal and chemical coal-desulfurization processes designed to yield refinable petroleum substitutes and solid fuels for boilers reduce the fuel's volatile matter content. This reduced volatility influences combustion characteristics such as ignition temperature, flame stability, and carbon burn-out.

A variety of studies has been conducted on the oxidation reactivity of coal char (1-5). On the basis of information available from these studies, it can be concluded that the conditons under which a char is prepared influences its reactivity. Some of the production parameters that affect the reactivity are processing gas, heating rate, maximum heat treatment temperature, soak time at peak temperature, and pressure. These factors influence the pore structure and active surface area of the char as well as the accessibility of a reactant gas to the internal surface area of the fuel during combustion or gasification. Recently it has been suggested that char formation conditions that result in a higher H/C ratio or hydrogen content favor reactivity (6-7).

The work presented in this paper is part of a larger study which was undertaken to determine combustion characteristics of partially devolatilized coals.

EXPERIMENTAL

<u>Char</u> - Chars, also referred to as partially devolatilized (PD) coals, were made from a bituminous coal sample obtained from the Illinois Basin Coal Sample Program, sample IBCSP-3 (8). The analysis of the coal is given in table 1.

PD coals were made in two ways: in a pilot-scale fixed-bed reactor at the United Coal Company (UCC) located in Bristal, Virginia, and in a microbalance reactor. The UCC samples were prepared under mild gasification conditions and had volatile matter contents (dry-basis) of 23.3%, (PD-1), 15.4% (PD-2) and 11.4% (PD-3), see table 2. The details of PD production at the UCC are given elsewhere(9). The samples made in the microbalance reactor were produced under the following conditions: heating rates between 5 and 1200°C/min; heat treatment temperatures (HTT) between 400 and 900°C; soak times at maximum treatment temperatures up to 4 hours. These fuels were prepared under nitrogen purge and had volatile matter contents between 2 and 30%.

<u>Reactivity measurement</u> - The particle size of samples was reduced to less than 90 micrometers prior to reactivity tests. An Omnitherm Thermogravimetric Analzyer (TGA) which was interfaced with an IBM-XT computer through a Keithley DAS series 500 data acquisition system was used to obtain burning profiles of the PD coals. In each experiment, a sample mass of about 2 mg was loaded in the TGA platinum pan and was heated at a constant heating rate of 20°C/min in air from ambient to temperatures up to 800°C. The flow rate of air was 200 cc/min (STP).

RESULTS AND DISCUSSION

<u>Burning profile</u> - The term burning profile was first used twenty years ago to refer to a plot of the rate of weight loss versus temperature when a small amount of coal-derived fuel is heated (usually 15-20°C/min) in air(10). Characteristic temperatures from the burning profile corresponding to the onset of burning, peak burning rate and complete burn-out were taken as a measure of a fuel's reactivity, with lower characteristic temperatures indicating more easily burned fuels. The test was used

with past experience and standard reference profiles to predict conditions, such as residence time or excess air, necessary for complete combustion of fuels in large furnaces. The burning profiles were found especially useful for evaluating combustion characteristics of unknown fuels when only small quantities of fuel were available.

In recent years, the concept of burning profiles has been used in coal combustion studies to show the effect of variations in coal rank on reactivity (11), to show the influence of maceral composition on combustion of pulverized coal (11, 12) and to determine the activation energy for oxidation of char (6, 7, 13).

Figure 1 shows typical weight loss and rate of weight loss data obtained in air for coal. The gain in sample weight between 200 and 300°C is due to oxygen chemisorption, i.e., preignition oxidation. A major weight loss began at 375°C (T_I). This temperature was taken at the point where the rate of weight loss was 1%/min. The rate of burning peaked at 490°C (T_P) and the coal was compeletly burned at 630°C (T_B). The burn-out temperature was taken at the point where the rate of weight loss was 1%/min. The weight remaining at 650°C was the ash content of the sample which was approximately 12%.

<u>Combustibility of coal and PD coals</u> - The burning profiles obtained for the coal, PD-1, PD-2, and PD-3 coals are shown in figure 2. The profiles are offset to avoid overlap. The onset of burning was about 375°C for all the samples. However, there are clear differences among the burning profiles. Raw coal exhibited a single-burn profile, while double-burn profiles were observed for PD-1, PD-2 and PD-3. The second burn appeared as a shoulder peak for PD-1 and became more pronounced for PD-2 and PD-3. The double-burn behavior observed for the PD coals suggested the presence of at least two types of combustibles in the fuels. The two portions of combustibles burned in two distinct stages with peak burn rates at approximately 500°C and 550°C. The higher reactivity constituent (low temperature burn) was a coal-like material and was present in larger concentration in PD-1 followed by PD-2 and PD-3 (9). It had burning properties similar to that of the coal. Fuels with higher volatile matter content burned more rapidly. For example at 500°C, the amount of combustible materials burned (not shown) was 70% for the raw coal, 55% for PD-1, 40% for PD-2, and 20% for PD-3. The most pronounced impact of the volatile matter was on burn-out temperatures which were 580, 630, 660 and 690°C for the coal, PD-1, PD-2 and PD-3, respectively. The results indicate that under the conditions used, raw coal was the most readily combusted fuel, followed by PD-1, PD-2 and finally PD-3.

Burning profiles of PD-2 and two 15% volatile PD coals are shown in figure 3. LTC was produced in the microbalance reactor by heating the coal at 5°C/min to 525°C. Coal+HTC was a mixture of coal and a high temperature char (HTC, 3% volatile matter) which was prepared by heating the coal at 5°C/min to 850°C, see table 2. The profiles for the coal and the HTC are also shown in figure 4. LTC exhibited a single burn behavior during burning in contrast with PD-2 and Coal+HTC which exhibited double-burn behavior. The peak burn rate for the HTC occured at 575°C which was 25°C higher than the temperature of the second burn obsorved for PD-2. This was because the HTC was subjected to higher processing temperature than PD-2. The burning profile for the Coal+HTC reveals that the two fraction of this fuel, i.e. coal and the HTC, burned in two stages with peak burn temperatures corresponding to those of the coal and the HTC. LTC was more reactive than PD-2 and the Coal-HTC fuel because it had a lower burn-out temperature. These results indicate that a fuel with inherent volatile matter is more reactive than a fuel with comparable volatile matter prepared by blending raw coal and low volatile char. This suggests that volatile matter alone cannot be used as an index of reactivity.

The influence of volatile matter on characteristic temperatures of PD coals which were made in the microbalance reactor are shown in figure 4. These fuels exhibited a single burn profile during combustion. The results show that there were only slight differences in characteristic temperatures for fuels with volatile matter contents above 10%. However, with further decreases in volatile matter, burn-out temperatures increased markedly. The burn-out temperatures were particularly sensitive to preparation conditions of a sample. Fuels prepared at the fastest heating rate, i.e. 1200°C/min, and shorter soak times were more reactive and had lower burn-out temperatures than those made at slower heating rates and longer soak times. These observations are in agreement with results reported in a previous study on the reactivity of PD coals derived from an Illinois hvB coal (1). The values of T_B for PD coals prepared at UCC are also shown in figure 4. It is clearly seen that these samples had higher burn-out temperatures than those prepared in the microbalance reactor under controlled pyrolysis conditions. The UCC samples were produced in a pilot-scale reactor and were subjected to different processing conditions than the PD coals made in the microbalance reactor.

CONCLUSIONS

Results obtained in this study suggest that PD coals with comparable volatile matter content produced from the same coal but under different processing conditions had different burning characteristics. Lower preparation temperatures, higher heating rates and shorter soak times at final pyrolysis temperatures favored reactivity. PD coals with inherent volatile matter were more reactive than fuels with comparable volatile matter prepared by blending low volatile char and the coal. It was also concluded that volatile matter alone may not be a valid index of reactivity.

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Table 1. Analysis of coal, wt% (moisture-free basis)

Coals	IBCSP-3
Seam	No. 5[1]
Rank	HVBB
Moisture	5.4
Volatile matter	39.2
Fixed carbon	52.4
Ash	8.4
Carbon	73.8
Hydrogen	4.9
Nitrogen	1.7
Oxygen	8.7
Sulfur	2.3
Chlorine	0.2
Heating value (Btu/lb)	13,437

[1] Predominantly Springfield (No. 5). Approximately 20% Herrin (No. 6) blended at washing plant.

Table 2. Volatile Matter Content of PD Coals and Their Preparation Conditions

Sample	Reactor Type	Temperature (°C)	Residence Time (hr)	Volatile Matter (%)
PD-1	Fixed Bed	760*	1.7	23.3
PD-2	Fixed Bed	760*	2.5	15.4
PD-3	Fixed Bed	760*	3.2	11.4
LTC	Microbalance	525	---	15.0
HTC	Microbalance	850	0.5	3.0
Coal+HTC				17.0

*Reactor tube (8-inch in diameter) was located in a natural gas fired furnace kept at 760°C.

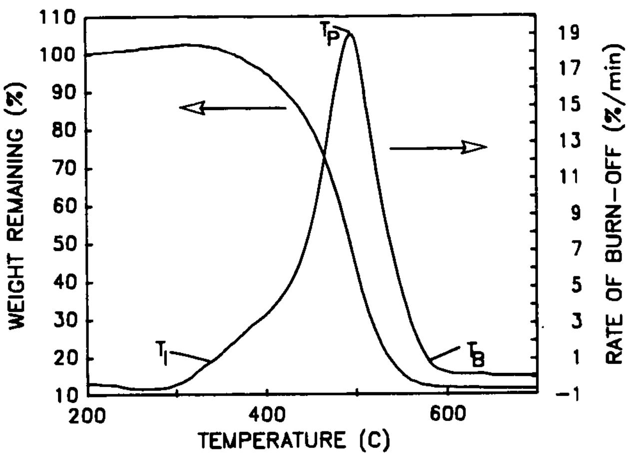

Figure 1. Burning characteristic of coal.

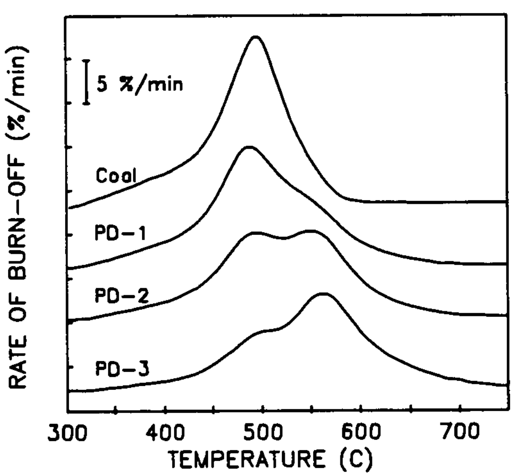

Figure 2. Burning profiles for coal and UCC PD coals

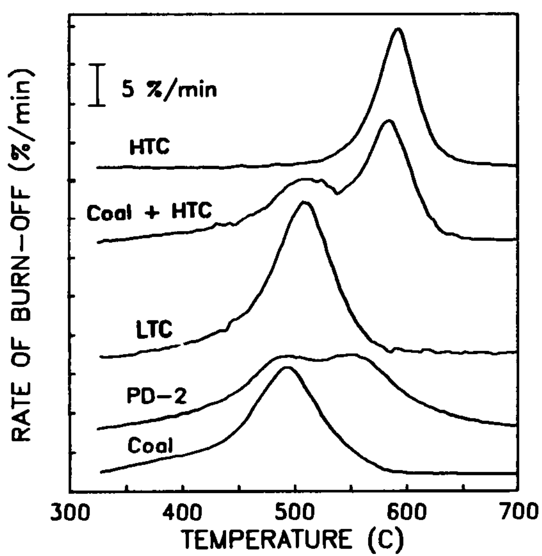

Figure 3. Burning profiles for coal, high and low temperature chars, and a mixture.

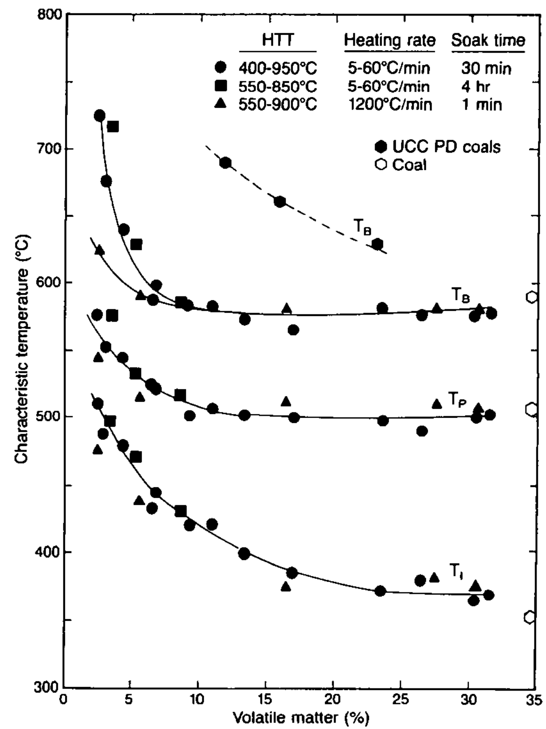

Figure 4. Effect of volatile matter on characteristic burning temperatures of chars produced under varing conditions.